Challenges of Creating a Verifiable Building Energy Model

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ABSTRACT

Conducting an energy model simulation for building systems design is indispensable when designing for optimal energy efficiency. Without a critical understanding of the potential energy limitations and waste that a building might exhibit, the substantial financial increase of a project might inhibit the growth of environmental conservancy and progress in business. Computational software operated by professionals helps to sustain that growth. The Science Engineering & Technology (ET) building on the Indiana University – Purdue University Indianapolis campus provided the model for this study and allowed observation of the usability of three distinct software packages -- eQUEST v3.65, Trace 700 v6.3.2, and EnergyPlus paired with OpenStudio V8.7.0 -- and a comparison of the end results with actual utility data provided by Campus Facility Services. This was an attempt to identify the main challenges that building energy modeling software has yet to overcome and to evaluate the merits of the software packages regarding ease-of-use, detail, accuracy, and modeling options. It is shown that the two biggest challenges are 1) creating a model that accurately represents the physical building and its internal systems, and 2) accurate representation of usage and conditions to which the building will be subjected. The former can be mitigated by creating more user-friendly programs with a better system of checks and balances to identify errors in the physical model. The latter is highly complex, often due to the lack of data acquisition to represent the past and the absence of exacting foresight into the uses and conditions of the building. The results show that energy consumption can be calculated with error ranging of 11%-21% with eQUEST, between 18%-90% with Trane Trace 700 and between 5%-20% with EnergyPlus.

INTRODUCTION

HVAC system operation in an educational institution can account for, on average, up to nearly 50% of the end-use energy consumption (Analysis and projection, U.E.I., 2012). The major components of energy consumption for a building are the HVAC systems and lighting. These features of energy consumption can vary widely depending upon the actual use of their respective systems by either schedule or occupancy.

Song et. al. (Song, Zhang and Meng 2015) performed the "Simulation and Analysis of a University Library Energy Consumption based on eQuest." They concluded that the largest energy consumer in a library was the HVAC system, which consume 49% of the total building energy, followed by lighting at approximately 15% of the total energy. Neto et al. (Neto and Fiorelli 2018) used EnergyPlus to make an energy model for an office building. Pedrini et al. (Pedrini, Westphal and Lamberts 2002) studied calibration of energy models for more than 15 office buildings and concluded that the actual schedules of the building have the most impact on the accuracy of the energy model.

Neto et. al. (Neto and Fiorelli 2008) compiled a "Comparison between Detailed Model Simulation and Artificial Neural Network" which was used for forecasting the energy consumption of the buildings. Emily M et. al. (Ryan and Sanquist 2012) stated that the accuracy of building energy models is very important to make buildings more energy efficient. In the research, they studied various validation methods, which are used in building energy modeling, and they studied the methods of estimating the effect of building occupancy on the building energy consumption. Pan et. al. (Pan, Yin and Huang 2008) simulated an energy model for two office buildings with data centers. Crawley et. al.

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(Crawley, Jon, Kummert and Griffith 2008) studied and analyzed an up-to-date comparison of twenty major building energy modeling programs. The research was based on data provided by the modeling program developers in 14 categories. Zhu et. al. (Zhu, Hong, Yan and Wang 2012) presented a technical report comparing three energy modeling programs; EnergyPlus, DeST, and DOE-2.1E. Detailed merits and demerits of each of the three programs were studied in the research.

From the literature review, it is apparent that there has been a significant amount of research in energy modeling using various programs. The authors of the research in this study found no comparative evaluation of eQUEST v3.65, Trace 700 v6.3.2, and EnergyPlus software and used their commonalities as a means of disseminating the challenges of creating a verifiable energy model.

CHALLENGES IN BUILDING MODELING

Following are the challenges experienced in building energy modeling.

Building Information (and Accuracy of Data): A significant challenge in modeling building energy consumption, usage, and waste is lack of information about the building that is being modeled. Missing or unreadable floor plans, system changes over time, and the absence of information regarding the system configuration within a building are significant obstacles. A study was conducted by M.D. Korovina at a Russian university in which they made three versions of a theoretical building. Each version was created with increasing detail, starting with two types of rooms followed by 9 types in the second and 17 room types/zones in their most detailed model. The maximum difference of energy consumption results between their most simplified and most complex models was less than 10% (Korovina 2017).

Program Usability: No matter how detailed one decides to make a model, one must be able to create it through a program's interfaces. The ability to master a program with efficiency is a critical skill. Swiftly being able to learn software and use it to one's advantage promotes quicker, more accurate results. When it comes to building energy-modeling software, it appears that nearly all of the programs fall short of a desired slope to the learning curve. Although frustrating, this situation is understandable. All the programs use in-depth coding in specific languages to handle their data. A major challenge is how to get that data to the core of the program to be processed.

(Graphical) User Interfaces: Some programs have minimal graphical user interfaces (GUIs) while some have extensive GUIs. Regardless of the type, they all have challenges. The more complex GUIs have many more options that are easily available; however, their complexity can often conceal some key features that can benefit the user.

Troubleshooting: A universal issue with building energy modeling software is troubleshooting errors. Due to the small group of users, forums have more unanswered questions than answers. The questions that are answered usually have solutions in the form of complex codes. "Workaround" is one of the most common non-technical terms used regarding solving issues within these programs. The term is self-explanatory: The solutions are not technical solutions that work through the problems but are cheats and shortcuts to get around the issue. Naturally, these workarounds could be the source of a significant divergence between model results and physical building statistics.

Model Simulation Behavior: There is no way to model human behavior exactly. This makes it impossible to account for the exact conditions that a building will be exposed to in its lifetime, a year, or even a single day. A door unintentionally left open for an extended period can lead to the unintended conditioning of a space. This will have a significant impact on the energy consumption designated for that space. Vents and ducts can be opened or closed at any time. Variable airflow can cause pressure differences that were not accounted for in the design, causing fans and blowers to work harder than necessary or to use less energy than designated in a model simulation.

Efficiencies of Actual HVAC/Distribution Equipment: In all programs, there are assumptions made by the program or data entered regarding efficiencies, and the model assumes that the systems will regularly run at those efficiencies. In reality, this may not be the case due to equipment age, broken parts, or a situation in which the system is subjected to conditions for which it was not designed.

Inexplicable Results from Simulations: Some results from simulations simply do not make any engineering sense. On occasion, software will assume that the most heat necessary for the building happens during the summer months or that almost no heat is necessary at all. Results such as these often make a user want to search for a solution to the problem even if other aspects of the simulation appear accurate, such as the cooling requirement.

SOFTWARE OVERVIEW

The ET building on IUPUI's campus incorporates space classifications such as Offices, Conference Rooms, Classrooms, Research Laboratories, Engineering Workshops, Mechanical/Electrical Rooms, Restrooms, etc. The floor-to-floor height is 17 ft., and the ceiling height is 9.5 ft. on most levels. The exterior wall is 2 ft. of concrete; the exterior door has 0.25 in. of uninsulated glass panels. There are 25 storage rooms, which do not have cooling. Per the ET building construction documents, space ventilation is supported by the operation of 39 exhaust fans. The major HVAC system type that the building incorporates is a multizone Air Handling Unit (AHU's) with single duct Variable Air Volume (VAV) system using hot water (HW) reheat.

Three programs were used to model the energy usage of the ET Building at IUPUI: eQuest, Trace700, and EnergyPlus. The model simulations of energy consumption by utility were then compared to see which software appeared to have the closest results to the actual utility data provided by IUPUI Campus Facility Services (CFS). The programs were also compared to the challenges explained above to see which is appropriate for the critical circumstances that could be present in a future case.

eQUEST

The eQUEST energy simulation program is a free downloadable application developed by James J. Hirsch & Associates that is unrestricted for use in private or commercial applications (Associates, J.J.H, 2018). It primarily consists of a Schematic Design [SD] Wizard and Design Development [DD] Wizard. In the SD Wizard, the program walks the user through 43 model input screens, each targeted at basic set-up of the energy model. The building simulation results that were obtained will later be discussed in further detail.

Trace 700

For purchase or membership, the Trane Corporation offers Trace 700 as a building energy and HVAC application simulation software and support via TraneCDS (Trane, Trace 700, 2018). It consists of 10 major project information entry portals and various sub-portal templates. Like eQUEST, project information and local and weather data by zone is offered by default with override designer options. Distinguishing it from eQUEST is that following the inputting of project information and overridable building floor constraints for internal load, airflow, thermostat, and construction, the process of entering space information is done on a room-by-room basis. Upon creation of the templates and inputs for 237 rooms, creations of two major HVAC systems was executed and adjusted for relevance. Each of the option tabs is easy to navigate and to input selections. In most cases, instructions or warnings are offered for items of note within the viewing window. The building simulation results that were obtained will later be discussed in further detail.

EnergyPlus – OpenStudio

EnergyPlus is a free software maintained by the U.S. Department of Energy (DOE) Building Technologies Office. Many universities, government projects and private firms have refined the program since its initial release. The most up-to-date version at the time of this study is 8.8.0 (U.S. Department of Energy, 2018). EnergyPlus allows for manual input through its ".idf file" editor subprogram; however, the software was designed for third- party user interfaces to be the main point of data input (Crawley, LKL, Pendersen, Winkelmann, 2000). To support this, both OpenStudio and Google SketchUp were used. Google SketchUp is a 3D modeling software that allows the user to create building objects and, most useful to our application, supports third-party plug-ins such as the one developed for OpenStudio. OpenStudio is a third-party open-source software developed by the U.S. DOE designed specifically for supporting the whole-building energy-modeling program EnergyPlus with the additional capabilities of advanced daylight analysis. The main objective of OpenStudio is to be a graphical user interface for engineers, building designers, architects, and others while simultaneously allowing its source code to be open-source to allow for manipulation by any software developer. OpenStudio/EnergyPlus sets itself apart in not just one but nearly all of these categories because it allows the user to be specific when designing the building. This program has not been developed to be a rough estimation but rather a near-exact approximation. The modeling of the ET building began in SketchUp, and each of the floors inside the exterior of the building are shown in the following figure 1.

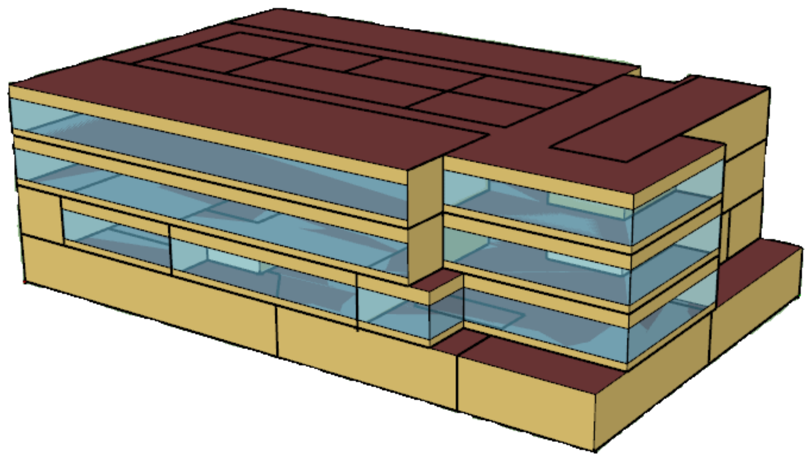


Figure 1 Building 3D model generated by Energy Plus

Following building modeling, schedules were created with careful consideration of how each space type is used. Load types and construction were made simple by the OpenStudio application. Loads were attached to space types by dragging and dropping from the software library. Software developers from around the world have developed the library, and standards have been implemented for specific types of buildings (Crawley, LKL, Pendersen, Winkelmann, 2000). Once the model was completed, simulations of the building with applied loads, heating, and cooling were run successfully.

RESULTS- ENERGY MODELING AND ACTUAL SITE.

eQUEST

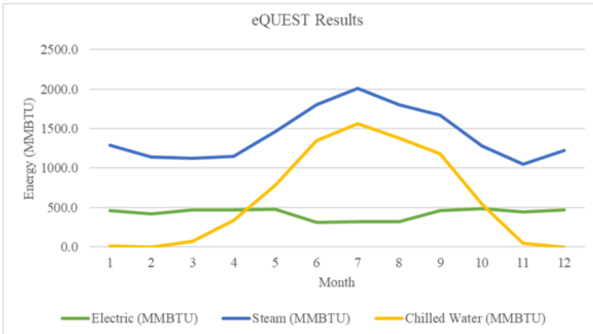
Monthly energy consumption simulation results by eQuest for the ET building is represented in Figure 2. Additionally, the program generated a 1109-page summary report.

Trace 700

A simulation was conducted which resulted in the option to create several distinct reports. System, room, equipment and peak cooling and heating reports were recorded and compiled with relative ease in clear, concise tabled reports. Monthly energy consumption for the ET building simulation is shown in Figure 3.

EnergyPlus – OpenStudio

The energy consumption simulation results for EnergyPlus are shown in the following Figure 4.



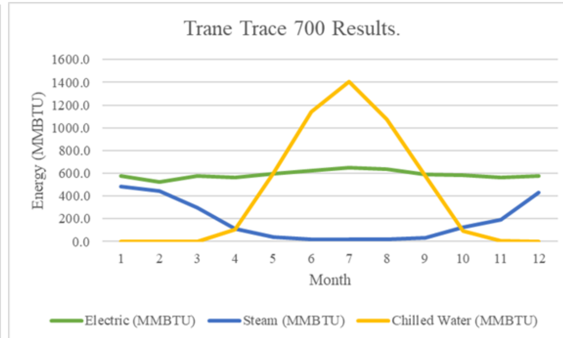
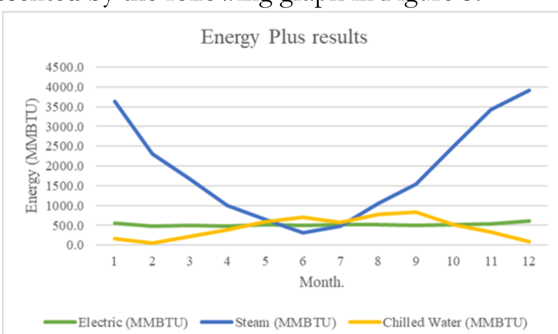


Figure 2 eQuest modeling results

Figure 3 Trace 700 modeling results

Actual Site Consumption

For comparison purposes, one year's worth of data for the ET building was acquired from Campus Facility Services and is represented by the following graph in Figure 5.



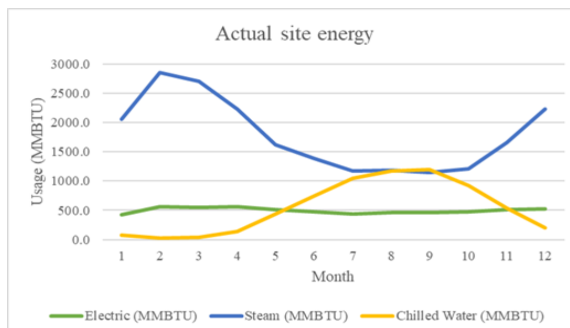


Figure 4 Energy Plus modeling results

Figure 5 Actual site energy consumption

SUCCESSES AND FLAWS

eQUEST

eQUEST exhibited some difficulty in program usability. The GUI demonstrates an attempt at a walkthrough of each step necessary to collect information for a simulation. The requirement to switch to the DD Wizard can be problematic if an error is made in previous steps. To correct such mistakes, the user must start the simulation over. Layout and other building information is possible to input -- however, complicated -- but exact geometry is not easily captured. The HVAC system layout issue is clearly present in this program, and attempts to overcome the difficulties were complicated, especially with limited troubleshooting assistance present on the web. eQUEST is not recommended by the authors of this study as a program to model building energy that requires a significant level of detail.

Trace 700

The Trace 700 GUI is user-friendly, and each interface is designed around a particular aspect of input relevance. A user guide is accessible by pressing "F1" and offers modelling assistance specific to the active interface along with a searchable database of engineering information. Each screen is simple and includes the minimum options necessary to perform calculations. Calculations can be executed without complete modelling data, and results can be viewed while simultaneously editing input for a subsequent iteration. The uses of templates can significantly reduce the redundancy of data entry. However, errors can occur during simulation that may cause the program to crash and/or to exhibit results that are inaccurate. The difficulty of these failures is compounded by the Trane Corporation's intention to no longer revise the software. The simplicity and the time saving aspects of the latest version, however, make it superior to eQUEST.

EnergyPlus – OpenStudio

This software is very in-depth and seemingly accurate. The number of variables that can be changed and the customization of every aspect of how the building can be modeled are good tools that can provide quite a challenge. Minimal explanation of each aspect of the software increases the difficulty of mastering the material. All aspects of the software allow modification at any point during the data entry process, which is helpful, especially if not all data has been collected when starting a project. Solutions to problems are answered in extensive code blocks in this program. In OpenStudio, assistance comes in scripted "Measures". These measures can read the program and change certain aspects. This saves significant time when dealing with repetitive data that may need to be entered or reassigned. The program usability and accuracy of EnergyPlus with the combination of OpenStudio surpasses all other programs.

DISCUSSIONS

Figures 6-8 present the results of each model that was executed through the model year on a month-to-month basis.

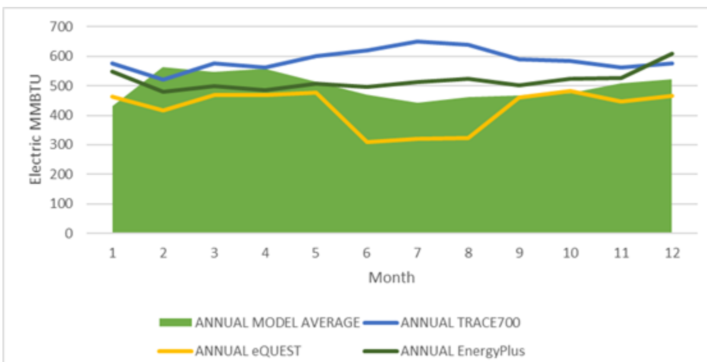


Figure 6 Energy model comparison: Electrical

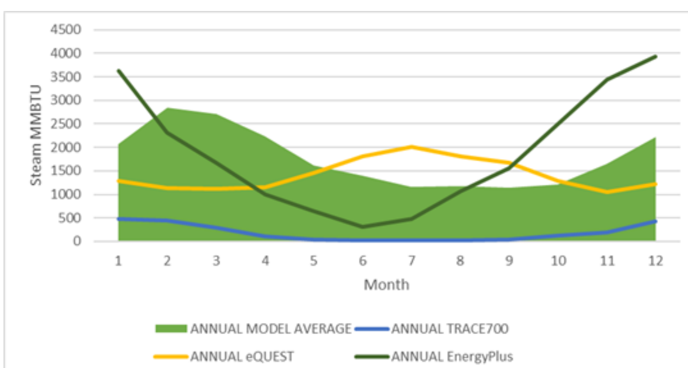


Figure 7 Energy model comparison: Steam

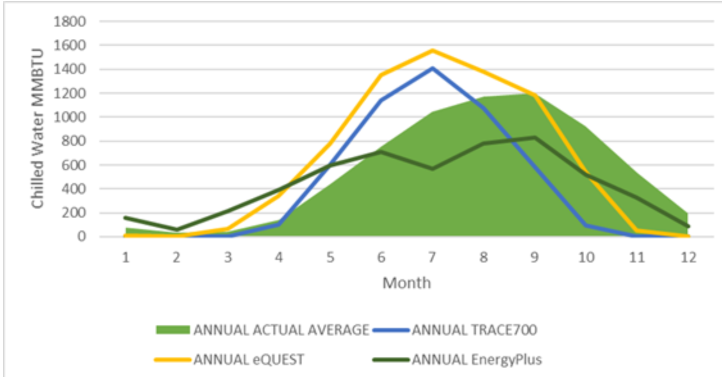


Figure 8 Energy model comparison: Chilled water

Table 1 shows the average error over the course of the year in each category.

Table 1. Error in Energy Models

ELECTRICITY [MMBTU]				
	Actual Site Energy	**TRACE700**	**eQUEST**	**Energy+**
Consumption Results	5968.2	7055.9	5102.5	6214.5
Total Error (MMBTU)	0	1087.8	865.6	246.3
% Error	0	18.23%	14.50%	4.13%
STEAM [MMBTU]				
Consumption Results	21442.68	2216.5	16990	22518.2
Total Error (MMBTU)	0	19226.2	4452.7	1075.5
% Error	0	90%	21%	5%
CHILLED WATER [MMBTU]				
Consumption Results	6550.5	5006.0	7260.0	5240.3
Total Error (MMBTU)	0	1544.5	709.5	1310.2
% Error	0	24%	11%	20%

The data in this table is a clear indication of the complexity of full building energy modeling and illustrates that such a task is still an outstanding challenge. The error observed in most of the results was less than 25% with the exception of the error for Steam Consumption for Trace 700, which was 90%. No valid reason could be found for this huge error, which relates to the potential flaw discussed earlier in Inexplicable Results from Simulations.

Since EnergyPlus was the closest model to reality, one additional piece of information identified, as a possible cause of error -- the Occupancy and Infiltration Schedules – needs to be examined.Viewing the plots of the actual consumption vs. the EnergyPlus model results, one could conclude that there is a high probability that the infiltration as well as occupancy schedule data are incorrect. Looking at the steam usage charts, one will find that in hotter months, the model predicted that less steam would need to be used for heating than reality. This error by the simulation could be the effect of overestimation regarding how much warm outside air would come in from outdoors. This extra outdoor air in the simulation would reduce the load on the HVAC systems to keep the space at the proper temperature. There is a similar assumption regarding the colder months: The simulation shows that more steam would be required to heat the building because more cool air would be entering the in the simulation than in reality. Making a similar case when viewing the chilled water usage charts is not as simple because the EnergyPlus model undershoots the actual data for most of the year. This is the case even in the summer months, which would disprove the previous theory. However, there is no data on other uses of chilled water besides HVAC which could account for such a large quantity [What does this mean?] missing from the simulation calculations. In the EnergyPlus model, the occupancy during the summer months was significantly decreased as well as the heat gain load from computers and equipment. This could be another cause of the simulation having a low approximation of the cooling power necessary.

CONCLUSION

Modeling the energy consumption of an entire building is an attempt to identify ideal energy use for the expected conditions. This effort is supported by the software and user acumen with respect to the professional design standards, which assist engineers in the task of designing for energy efficiency and cost effectiveness. At the completion of this study, it is well understood that additional adjustments and verifications of the model-building relationship should be made to conduct a more accurate energy consumption prediction of the Engineering & Technology building on IUPUI's campus. Many of the qualities of each software package are attributed to the adherences to industry design standards that are irreproachable. Strides have been made in recent years to increase the transparency of the effects of various design implementations on building energy use with slow, but increasing, success. Many iterations of the modeling process were completed in each of the three programs, and each brought the results closer to the verifiable numeric data. Changes in the use and occupancy of the building resulted in the greatest accuracy increases; however, these are the most unpredictable pieces of the modeling dilemma. Perhaps the researchers at the University of Hong Kong have stated it best: "There is limited understanding of buildings' energy use at normalized level and its relationship with various building parameters" (Yu et. al. 2015).

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